The impact of limited budget on the corrective action taking process

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1 Introduction

The main goal of project control is to identify the deviations between the baseline schedule and the actual progress of the project by measuring the project performance in progress, and using the project control methodologies to generate warning signals that act as triggers for corrective actions to bring the project back on track. To that purpose, tolerance limits are set on the required project performance, such that if the warning signals exceed these limits, they should result in appropriate corrective actions. However, the corrective actions always directly result in additional costs (reassignment of highly-skilled personnel, extra equipment, improvement of manpower, etc.) during project progress. The budget used for taking corrective actions is always limited in practice. In order to make the best use of the limited budget, they should be allocated in an efficient and effective way to repair the project delays. In this paper, four different approaches are proposed to allocate the limited budget to take corrective actions with the aim of improving the expected project outcome.

2 Problem formulation

The research on controlling projects with Earned Value Management (EVM) has grown in the last decades, and the topic has been investigated from different angles. The basic and more detailed aspects about EVM can be found in several studies (Anbari 2003, Fleming and Koppelman 2010). Although these performance measures in the EVM methodology detect deviations from the project plan, they do not notify the project manager whether these deviations are acceptable or not. Therefore, tolerance limits should be set up in conjunction with the EVM metrics in order to support the project manager to carry out corrective actions when necessary. Tolerance limits prescribe whether the measured project performance is acceptable or not, such that the project manager can decide whether corrective action is necessary. These tolerance limits can be classified into three types in literature according to their complexity (by the type and amount of data required together with the statistical tool used to analyze these data) and their abilities in predicting the need for actions, namely the *static tolerance limits*, *statistical tolerance limits* and *analytical tolerance limits*. For a detailed comparison and evaluation for these three types of tolerance limits for project control, the reader is referred to Vanhoucke (2019). When the tolerance limits are exceeded, the project manager should decide whether to take corrective actions or not. Vanhoucke (2010) presents a simulation study with corrective actions on the selected highly sensitive activities by reducing the activities' delay to half of their baseline duration. However, reducing an activity's duration normally leads to increased cost and this is known as *activity crashing*. The computational results have shown that corrective actions taken on highly sensitive activities are more reliable for parallel projects, but lead to poor contribution for serial projects. In order to provide a better alternative to the poor behavior of these corrective actions for more serial projects, Vanhoucke (2011) extends this research by introducing the concept of control efficiency for corrective actions and compares two alternative methods in a simulation study. The author still relies on activity crashing as the only way of taking corrective actions. Moreover, the author shows that EVM is more reliable for serial projects than for parallel projects. Hu *et. al.* (2016) implement corrective actions on selected sensitive activities by reducing the baseline activity duration proportional to activity sensitivity information to revise the project delay.

Despite the growing amount of literature on project control with corrective actions, to the best of our knowledge, none of these studies discussed previously have explicitly taken the limited availability of budget for taking corrective actions into account. Due to the presence of a budget constraint, not all the corrective actions are able to be taken timely when the current project performance is not acceptable, and this might have a negative impact on the project outcome. Consequently, the central question of this paper is how the limited budget can be best allocated, such that it can support the project manager to take efficient corrective actions to improve the expected project outcome.

This paper presents four different approaches to allocate the limited budget according to different project characteristics. More precisely, the *Earned Value* (EV) approach makes use of the earned value methodology to allocate the limited budget according to the cost information of each project phase. The *Earned Schedule* (ES) approach allocates the limited budget using the earned schedule methodology which measures the time and cost information of the project. The *Earned Duration* (ED) approach uses the earned duration methodology to allocate the limited budget based on the time information of the project. The *Activity Risk* approach (AR) uses the risk information of each individual activity to allocate the limited budget.

3 Methodology

3.1 Data generation

In order to test the impact of limited budget on the corrective action taking process, a set of 900 fictitious project networks with topological structure are generated by a project network generator RanGen (Demeulemeester *et. al.* 2003, Vanhoucke *et. al.* 2008). The dataset is extensively applied in previous project control simulation studies (Ballesteros-Pérez *et. al.* 2019, Elshaer 2013). The topological structure of these fictitious project networks are presented by the serial/parallel (SP) indicator, which is used to measure the closeness of a project network, and contains 100 projects for SP = 0.1, 0.2,...,0.9. More specifically, project networks with low (high) SP values are close to parallel (serial) projects. Each project network consists of 30 activities. For each activity, the fixed cost is uniformly sampled between €10 and €90, a variable cost is uniformly sampled between €100 and €900.

3.2 Setting tolerance limits

The tolerance limits are constructed by assuming that the project buffer of a certain percentage of the planned duration is consumed proportionally to the PV accrue of each project phase. More specifically, when the project is completed at x% of the BAC, x% of the project buffer is allowed to be consumed for that phase. This approach is developed by Martens and Vanhoucke (2017). In this study, the tolerance limits are set for project buffer sizes of 15%, 25% and 35% of the PD to simulate the frequency of warning signals in the project.

3.3 Simulated project execution

With the aim of generating a large set of fictitious project executions, Monte Carlo simulations are employed to generate project information with the presence of uncertainty. We will use the lognormal distribution which is skewed to the right to model the real activity duration (Hu *et. al.* 2016, Bie *et. al.* 2012, Kotiah and Wallace 1973), with $\mu = 1.1$ and $\delta = 0.3$.

3.4 Corrective actions

When a warning signal is generated during project execution, an action will be taken at that control phase. In this case, the estimated remaining duration of the eligible activity will be reduced under strict predefined limits. In the simulation experiments, three reduced levels of duration are considered and compared (i.e. 30%, 50% and 70% of the estimated activity duration) in order to simulate different degrees of corrective actions.

4 Results

In the experiment, the time efficiency is used to assess the ability of each approach to reduce the real project duration within the same control effort, which has been introduced in Vanhoucke (2010). The time efficiency is measured as a ratio between the total reduction in the project real duration after taking corrective actions ($RD^{no} - RD^{yes}$) and the sum of reduction in the activities due to crashing ($RD_i^{no} - RD_i^{yes}$), as described in Eq. (1).

$$time\,efficiency = \begin{cases} 0,\ if\ denominator = 0 \\ \frac{1}{nrs_w}\sum_{k=1}^{nrs_w}(\frac{RD^{no}-RD^{yes}}{\sum_{i=1}^{nract}(RD_i^{no}-RD_i^{yes})}),\ otherwise \end{cases} \quad (1)$$

With nrs_w the total number of projects with warning signals. As can be seen from this formula, the time efficiency equals to 1 when the reduction in real project duration is equal to the total change in all evaluated activities, which is a desirable state. Moreover, the time efficiency can be also equal to 0, when the total change in all the activities has no effect on the real project duration (numerator = 0) or when no corrective actions are taken when warning signals generated, due to a lack of available control budget (denominator = 0).

First, the computational results show that the ED approach (39.12%, Avg.) outperforms on average the other three approaches (EV: 29.13%, ES: 37.36%, AR: 38.11%). This ED approach allocates the limited budget according the to earned duration metric, and generates warning signals using tolerance limits set of the duration performance index DPI. It has already been shown in Batselier and Vanhoucke (2015) that this ED-DPI approach performs well for predicting the total project duration, but now it shows that it also performs well when taking corrective actions under a limited budget. Hence, our study confirms previous results, and shows that using earned duration management performs well both for project duration forecasting and for taking corrective action to bring projects back on track.

Second, the results show that the time efficiency decreases when the buffer size grows. When a relatively small buffer size is added at the end of the project, the project performance in progress will be frequently exceeded by the dynamic tolerance limits, and even the presence of small delays in the projects will result in more corrective actions in dynamic project progress. However, in case of a relatively large buffer size, the project performance measures seldom drop below the tolerance limits to generate warning signals to take corrective actions. In these cases, a false signal (i.e. project delay due to serious delay in non-critical activities which has little impact on the project duration) will have a larger influence (negative) on the time efficiency.

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